Quench Protection for High Field Magnets (>12T) (Accelerator Type)

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Conditions assumed in talk

- Protection to be accomplished by a close proximity heater
- Highly efficient coil winding package J_{cu} > 1000 A/ mm^2
- Examples given will be limited to Nb_3Sn coils. “Should be applicable to other A-15’s”
- Heater constructed composites of Kapton/ SS(cu)/ Kapton plus glue

Definitions

Conductor Miits	≡	10^6 Amp^2 -sec to reach 450 K a) measured b) adiabatic calculation
Critical ramp rate	≡	Rate of current change at which conductor exceeds its critical temperature of the average winding field in a 0.1 operating current loss
Minimum ProtectionWinding volume transitioning	≡	That length of conductor which will result in a L/ R time constant that will stay below the conductor Miits budget

Design input needed

Conductor

- dimensions
- composition
- geometry
- critical current, field, and temperature profile

Windings

- operating current, (load line)
- geometry
- electrical parameters
- magnetic parameters

Note: Any of these can be obtained by measurement (all the better) or calculated. Operational characteristics LHe II or I, open or closed winding.

Comment: (will not consider cryostable operating point coils due to time constraints)

Typical Design of a heater for a Nb_3Sn Race Track Coil

Conductor Parameters:

26 strand cable

0.8 mm strand diameter

J_c(non-cu) = 2000^+ amps/mm^2

Typical design input:

Quench output page

Typical Miits Curve:

Quench's Miit's Curve RD3

First order heater considerations RD3:

Induct. = 18mh

L/R = ?   at 10kA/turn yields 100 Miit's/sec

Miit's limit "Quench" =12.4

=> 125 milliseconds

- 40 " detection & diffusion

85 "

=>0.17 seconds = *t*(effective)

R = 0.018/0.17 ~ 0.1 ohms

Outer coil's room temperature resistance = 0.75 ohms

20K R(expected) = 0.02 ohms

20K R(measured)= 0.058 "

=> ¼ of the coil driven normal will work

“Quench” code input/output for Miit’s

COMPONENT PROPERTIES

FRAC	THETA	A	AEX	B	BEX	C	CEX	D	DEX	EMAG
.4093	.00	.4250E 07	.0300	.1670E 11	2.6900	.9000E 05	3.0000	.0000E 00	.0000	1.0000
.4093	45.00	.4250E 07	.0500	.1670E 11	2.6900	.2300E-02	1.5000	.0000E 00	.0000	1.0000
.4093	150.00	.1380E 06	1.2300	.0000E+00	.0000	.3000E+01	.0000	.1200E-03	1.0000	1.0000
.0713	.00	.1700E-05	1.200	.1670E-11	2.6900	.9000E-05	3.0000	.0000E-00	.0000	1.0000
.0713	45.00	.1700E-05	1.200	.1670E-11	2.6900	.2300E-02	1.5000	.0000E-00	.0000	1.0000
.0713	150.00	.1700E-05	1.200	.0000E+00	.0000	.3000E+01	.0000	.1200E-02	1.0000	1.0000
.3120	.00	.1000E+11	.0000	.0000E+00	.0000	.1900E-03	2.4000	.0000E-00	.0000	.0000
.3120	15.00	.1000E+11	.0000	.0000E+00	.0000	.4400E-02	1.7000	.0000E-00	.0000	.0000
.2063	.00	.6100E-04	.0000	.0000E+00	.0000	.7400E-04	2.2700	.0000E+00	.0000	.0000
.2063	90.00	.6100E-04	.0000	.0000E+00	.0000	.5400E-00	.2400	.0000E+00	.0000	.0000

INITIAL CURRENT= 10000.00 INIT. PROT. R.= .0550 GAMMA .00 T. CUTOFF=3000000.00 COIL IND. .0100

INIT. VELOCITY= 5210.33 UNIT CELL AREA = .155900 INITIAL TEMPERATURE = 4.5000

ALPHA = .00500 INIT. X VELOCITY= 358.4250 EPSILON= .76000 INIT. Y VELOCITY= 4601.6390

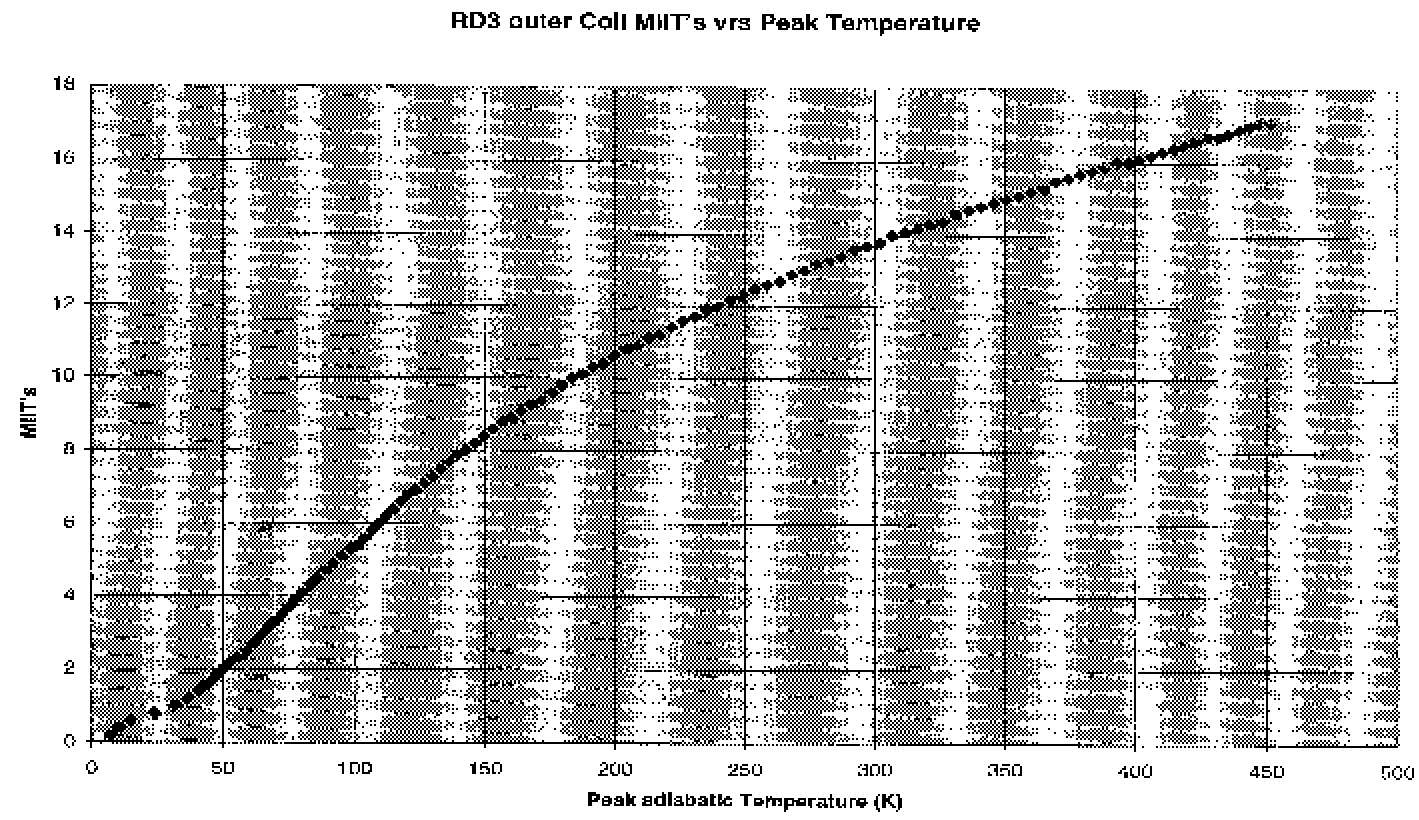
X COIL DIMENSION= 8.00 Y COIL DIMENSION= 1.16 Z COIL DIMENSION= 172.30

COORDINATES OF SOURCE X= 1.50 Y= .00 Z = 86.20

BREAKER DELAY TIME = .50 INITIAL MAGNETIC FIELD= 117.600KG

TIME	CURRENT	COIL RESISTANCE	DELTA VOLUME	EXT. VOLTAGE	INT. ENERGY	INT. VOLTAGE	THETA	LEQUI
.001000,	9999.99,	.4352995E-04,	.9350323E+01,	0,	4.36,	.44,	5.01,	.1,
.002000,	9999.92,	.9303260E-04,	.1046623E+02,	0,	9.30,	.93,	7.15,	.2,
.003000,	9999.93,	.1755167E-03,	.1744357E+02,	0,	17.55,	1.76,	9.94,	.3,
.004000,	9999.66,	.2412990E-03,	.3443077E+02,	0,	24.13,	2.41,	11.42,	.4,
.005000,	9999.49,	.4417965E-03,	.3159733E+02,	0,	44.18,	4.42,	16.26,	.5,
.006000,	9999.07,	.6262967E-03,	.3957333E+02,	0,	62.63,	6.30,	24.25,	.6,
.007000,	9999.80,	.9511942E-03,	.4574033E+02,	0,	95.10,	9.52,	28.21,	.7,
.008000,	9997.99,	.1114983E-02,	.5233108E+02,	0,	111.42,	11.14,	31.27,	.8,
.009000,	9997.10,	.1417993E-02,	.5929358E+02,	0,	141.71,	14.17,	35.82,	.9,
.010000,	9999.33,	.1721533E-02,	.5744098E+02,	0,	172.06,	17.21,	36.04,	1.0,
.011000,	9999.10,	.2042053E-02,	.5967948E+02,	0,	204.05,	20.41,	38.02,	1.1,
.012000,	9993.78,	.2385297E-02,	.6107538E+02,	0,	236.39,	23.95,	39.97,	1.2,
.013000,	9992.24,	.2757577E-02,	.6390108E+02,	0,	275.41,	27.56,	41.47,	1.3,
.014000,	9990.49,	.3157137E-02,	.6609948E+02,	.0,	315.23,	31.55,	42.99,	1.4,
.015000,	9988.50,	.3577951E-02,	.6991558E+02,	.0,	357.30,	35.76,	44.47,	1.5,
.016000,	9986.30,	.3979324E-02,	.6093828E+02,	.0,	397.01,	39.75,	45.92,	1.6,
.017000,	9983.87,	.4275143E-02,	.5764318E+02,	.0,	436.61,	43.73,	47.35,	1.7,
.018000,	9981.21,	.4782693E-02,	.5570008E+02,	.0,	475.95,	47.76,	49.75,	1.8,
.019000,	9978.32,	.5199450E-02,	.5458558E+02,	.0,	517.09,	51.96,	50.14,	1.9,
.020000,	9975.21,	.5626837E-02,	.5342658E+02,	.0,	560.70,	56.34,	51.30,	2.0,
.021000,	9971.85,	.6064417E-02,	.5269138E+02,	.0,	603.47,	60.49,	52.85,	2.1,
.022000,	9968.24,	.6514468E-02,	.5210768E+02,	.0,	647.78,	64.96,	54.19,	2.2,
.023000,	9964.38,	.6977220E-02,	.5168718E+02,	.0,	693.31,	69.55,	55.72,	2.3,
.024000,	9960.25,	.7453768E-02,	.5135518E+02,	.0,	740.09,	74.37,	56.95,	2.4,
.025000,	9955.86,	.7944618E-02,	.5082888E+02,	.0,	788.14,	79.13,	59.16,	2.5,
.026000,	9951.17,	.8150830E-02,	.5060920E+02,	.0,	837.53,	84.13,	59.47,	2.6,
.027000,	9946.22,	.8972510E-02,	.5053640E+02,	.0,	888.51,	89.29,	60.78,	2.7,
.028000,	9940.97,	.9511380E-02,	.5013540E+02,	.0,	940.33,	94.60,	62.09,	2.8,
.029000,	9935.41,	.1006750E-01,	.4993430E-02,	.0,	994.30,	100.09,	63.38,	2.9,
.030000,	9929.59,	.1061210E-01,	.4975460E-02,	.0,	1050.51,	105.75,	64.69,	3.0,

RD- 3 outer winding cable Miit's Curve



Protection of D20

A very conservative approach was taken:

70% of the magnet was under heaters

The power levels were for SF operation

Layer 1 = 53 watts/cm^2

Layer 2 = 23 “

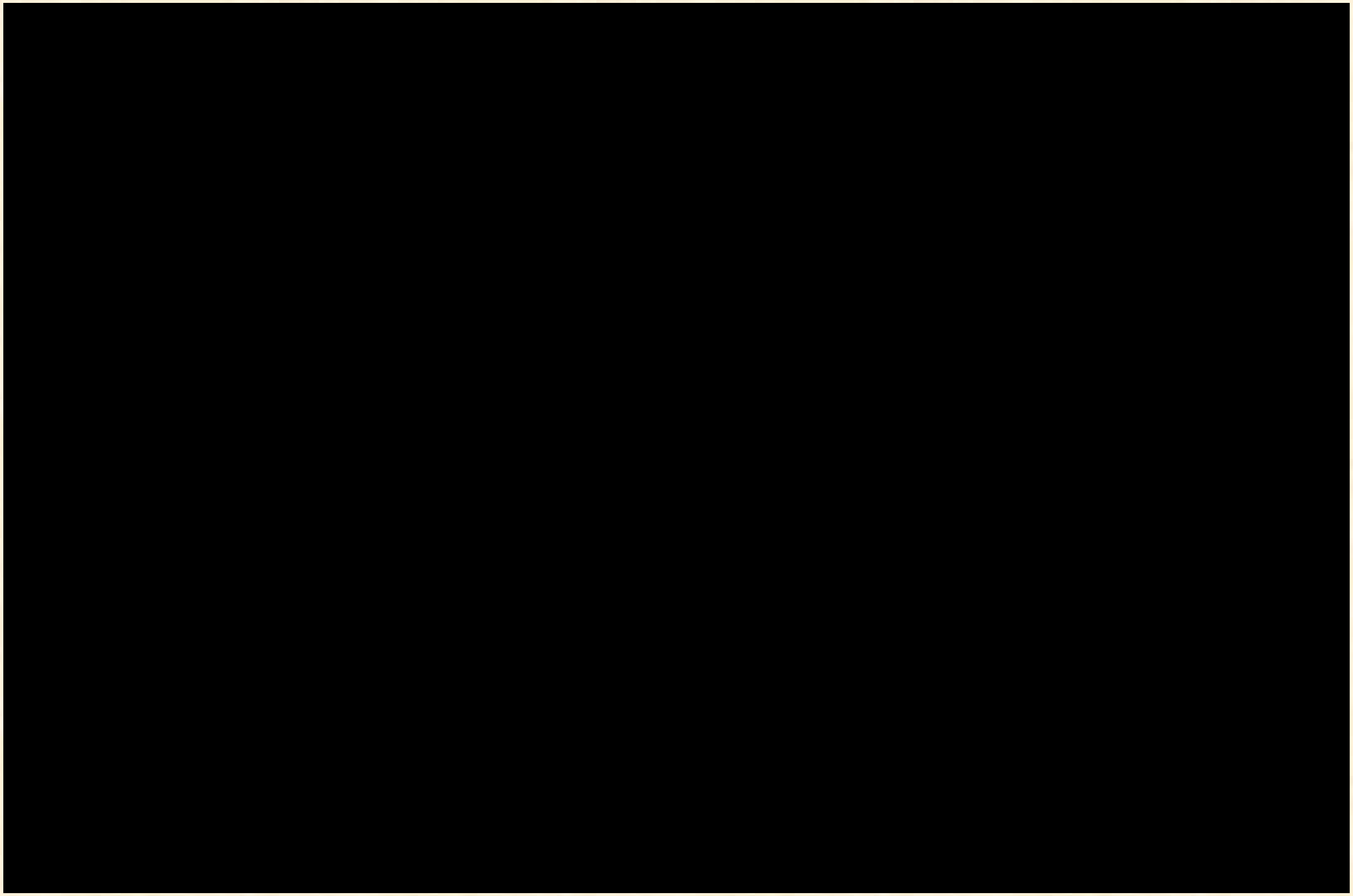
Layer 3 = 29 “

Layer 4 = 27 “

The data for Quench was:

The Miit’s Curve:

Miit's Curves for C0/D0 Quads, Tev, & D20



Integrated Stainless Steel Specific Heat versus Peak Temperature

Table

Temperature Adiabatic(K)		Energy/unit volume joules/cubic centimeter
100		80
200		316
300		642
400		1034
500		1494
Kapton Failure	770	2700

Typical Resistivity (Stainless Steel)		50 micro-ohm-cm
	RRR	1.5
Typical Time constants (1/e)		
Heater pulse		30 – 10 milliseconds
Typical detection plus thermal		
Diffusion time at 70% short Sample		40 milliseconds
(typical peak Miit value)		
Typical heater Power supply		450v
Parameters (x2 if stacked)		2 to 20 millifarad

Summary of typical process

Obtain Miits curve for magnet	Calculate from “Quench” code or Measure the 450K point
Calculate minimum coil volume	I (operate), L (millihenries)
Design heater area greater than that to switch min. coil vol.	Heater area calculated
Heater design resistances calculated	ohms to few 10’s of ohms
Temperature (heater) targets	150K to 200K
Wattage (heater) at the surface	≥20w/ cm^2 for LHe & ≥40 for SFHe
Time (heater) constants	30 millisec. to ≤100 millisec.

An efficient heater should:

Include an active length (non-cu plated)	≥1 cable transposition length
Minimum heater thickness (ss)	13 micron preferred, but 25 micron is normal
Min. thickness Kapton under layer and/ or	15 microns (≥3 kV checked)
Alumna filled Kapton (x2 thermal conduct.)	“ 3kV?

Can include diagnostic wiring traces